EXPECTED SERVICE LIFE FOR CONCRETE BRIDGES EXPOSED TO CHLORIDES, A FIELD STUDY

Alf Andersen[1]
Chalmers University of Technology, Division of Building Materials
S-412 96 Göteborg

SUMMARY

Even though the new observations are accurate the available data are few and the findings should be treated as indications. The five years of further exposure of the bridges gave no significant increase in the chloride ingress. In this investigation the position of the sampling point is more important than the increase in exposure time of the bridge.

The distance from the road seems to be an important factor, both horizontally and vertically. Orientation of surfaces towards traffic splash and driving rain is also indicated to be an important factor. Chloride penetration clearly is a function of exposure conditions, both chloride (intensity) and climate (wetness).

The parts of the bridges that were examined in this study, and the previous ones, are obviously fairly dry, properly because they are not significantly exposed to driving rain nor direct splash from the traffic.

The chloride exposure for the columns beneath a bridge seems to be mainly airborne chloride following the air stream in the direction of the traffic. Other parts of bridges more exposed to direct splash of salt water could be very much wetter and provide better conditions for deeper chloride penetration.

Keywords: concrete bridges, chloride ingress, corrosion

1. INTRODUCTION

In situ measurements in existing bridges and structures are an important part of developing valid models. The complexity of the mechanisms and the environment makes it important to isolate the decisive parameters and to simplify them with a minimum of distortion. This can be done by studying real structures and try to imitate the observations with mathematical models and laboratory measurements of the decisive parameters.

1.1 The Road Environment

The conditions in the road environment are summarised in Nilsson et al. [1996]. The distribution of chloride (concentrations at different depths) is a time dependent function of the

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[1] M.Sc.

environmental conditions, the design of the structure and the material properties. The mechanisms of chloride transport and binding involved are complicated and usually combined in a complicated way. The processes are not always understood and still not easy to quantify.

The transport and distribution of chlorides in a concrete structure is very much a function of the environmental conditions, mainly the concentration and duration of the solutions in contact with the concrete surface. The conditions are quite different in different exposure situations.

Salt water can be sucked into the concrete surface. Rainwater washes the surface free from chlorides and may remove some of them. Evaporation increases the concentration. Chlorides move inwards and outwards due to moisture flow and ion diffusion.

The conditions are different at different heights from the road level. A maximum chloride content may be found at a height where salt water is frequently supplied to the surface but where the surface intermittently dries out.

Bridges and road structures that are exposed to de-icing salts have boundary conditions that vary with time. In wintertime parts of the structure are exposed to saturated salt solutions that are rapidly diluted as the ice and snow melts. This exposure can be repeated frequently, sometimes once a day. Rainwater washes the surfaces and move salt water to drains and/or other parts of the structure.

Salt water penetrates cracks and joints very easily. Consequently, the occurrence and the effect of defects must be considered in the evaluation of the behaviour of a structure.

2. INVESTIGATED BRIDGES

The five bridges in this investigation were all examined earlier and they were not repaired or in any other way altered in the time from the previous and until this examination. The data regarding four of the bridges are published in Henriksen et. al [1991]. The data regarding the fifth bridge were unpublished until this report.

Big efforts were invested in taking the new cores as close to the previous cores as possible. This was not always the best point in view of the purpose of this investigation. The distance to earlier sampling points had to consider structural safety by not cutting reinforcement and available space for the drilling equipment.

2.1 Summary of bridges

Data on the age and conditions (quantitatively) for the bridges are given in table 3.6.1.

Table 3.6.1 Salt and traffic data from 1990 (except bridge 14-0036), Henriksen et. al. (1991)

Bridge No.	Built year	salt/year kg/m^2	Traffic units/ day	Lanes	Safety lane
14-0036	1956	1.0	36400	4	no
40-0004	1956	0.9	9000	4	no
30-0016	1972	0.6	17000	4	yes
10-0031	1968	1.1	46000	8	no
20-0085	1963	0.8	10000	4	yes

3. RESULTS

3.1 Chloride penetration depth, diffusion coefficients and carbonation depth

The chloride penetration depths, diffusion coefficients and carbonation depths from all the bridges are shown in Table 5.6.1. The penetration depth of the concentration 0.05% vs. age is plotted in Figure 5.6.2.

Table 5.6.1. Chloride penetration depths, carbonation depths and chloride diffusion coefficients for the cores taken from the bridges. $x_{0.05}$ is the depth where the chloride content is 0.05 % by weight of sample.

Bridge build	Sampling date	Core Mark	Height above road level [m]	$x_{0.05}$ [mm]	x_{CO3} [mm]	D_{CTH} [x 10^{-12}m^2/s]
10-0031	960512	1	0.2	>20	2	
1968	960512	2	0.2	26	0	8.2
	960512	3	0.0	32	0	
	9103		0.2	37		
30-0016	960425	1	0.5	20	-	10
1972	9103		0.2	7		
20-0085	960511	1	0.3	6	7-14	
1963	960511	3	0.1	26	5-15	35 and 32
	960511	4	0.7	35	7-10	79 and 37
	9103		0.3	0		
40-0004	960526	"20"	0.2	25	0	
1956	960526	"33"	0.3	28	0	
	9103		0.15	18		
14-0036	960619	S	1.3	23	4	7.5
1956	960619	N1	1.3	8	2	9.0
	960619	N3	0.2	24	2	4.6
	960619	N4	1.9	12	3	
	911002	S	1.0	16		
	911002	N	1.0	10		
	920520	S	1.0	17		
	920520	N	1.0	11		

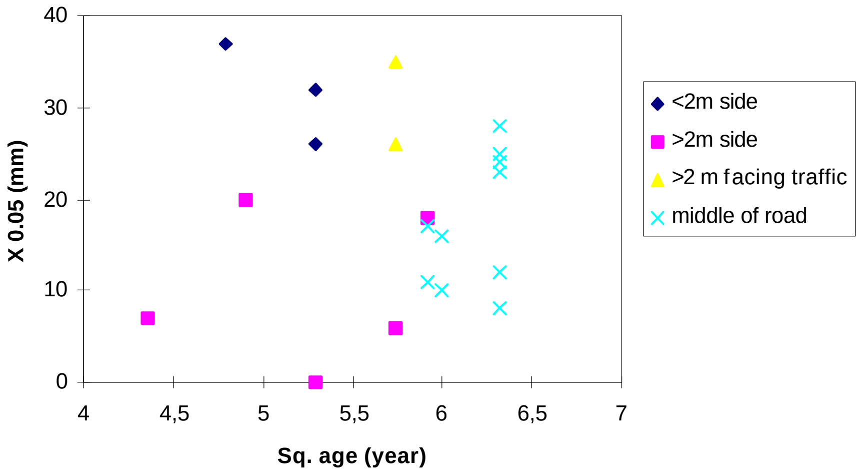

Figure 5.6.2 Chloride penetration ($x_{0.05}$) vs. age in all bridges.

4. DISCUSSION

4.1 Reproducibility

The analysis techniques are destructive, so exactly the same spot can not be examined more than one time. In this study effort has been put into taking cores as close as possible to the previous cores. In no case the distance exceeded more than 0.3 m vertically and 0.5 m horizontally. Avoiding cutting reinforcement bars was the single most important factor in adding distance between the cores.

Moisture analyses in field conditions are difficult and the results are depending on weather conditions on the sampling site. The profiles could be used as an indication on the accuracy of the technique used. Conclusions should always be drawn from several measurements (points in a profile).

Even concrete made in laboratory conditions and exposed to chloride (NT build 443) shows different chloride surface contents. The difference in double samples in Frederiksen [1996] was around 5 to 20 percent in most cases. Better results from field studies can not be expected, due to inhomogeneity both in concrete and exposure conditions.

Comparing chloride profiles could lead to strange conclusions in some cases. Due to an accident when drilling the cores from bridge 10-0031 a 20 mm long core (core 2) was obtained from the surface close to core 1 on the same bridge. Comparing the chloride content per sample indicate a significant difference in chloride content in the surface, figure 4.1.1. But if the chloride content is plotted vs. calcium content the difference in chloride profiles is smaller, see figure 4.1.2. This indicates that difference in binder content should be treated as an important factor close to the surface. The binder content varies in the cores especially in the surface area.

At depths larger than 10 mm the reproducibility is good.

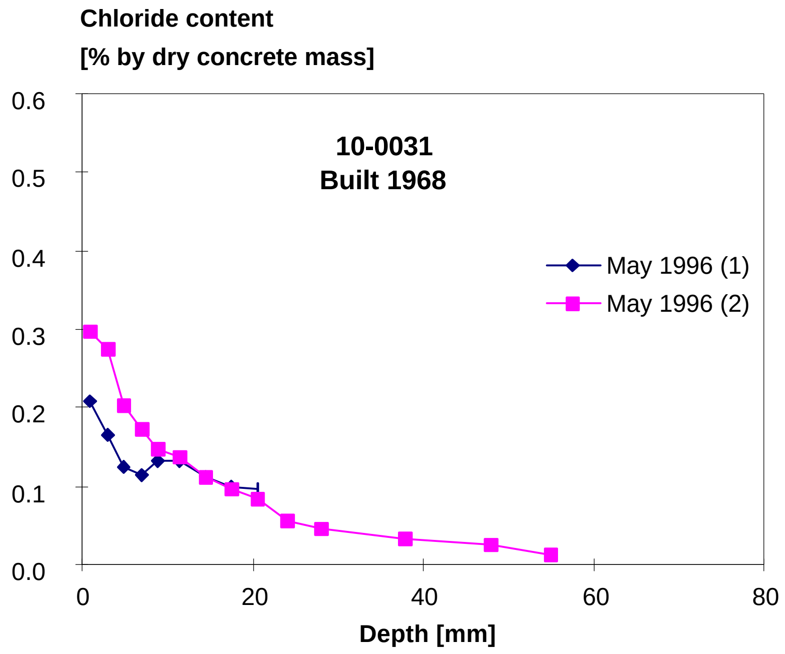

Figure 4.1.1 Chloride profiles from bridge 10-0031 in cores taken close to each other.

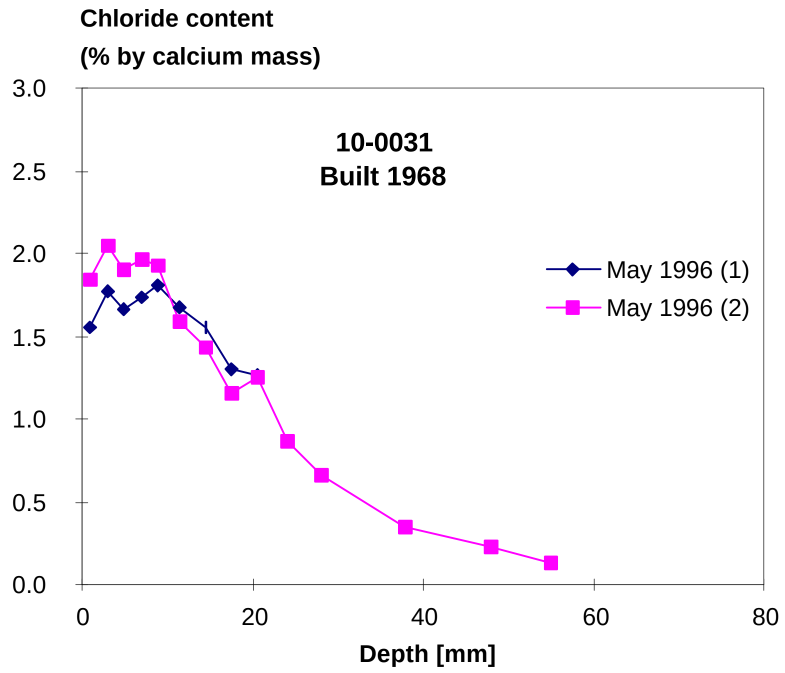

Figure 4.1.2. Chloride vs. calcium profiles from bridge 10-0031.

4.2 Effect of concrete quality

Even though the exposure may well have been quite different the concrete composition is expected to be quite similar (e.g. mix of plain Portland cement with no mineral additions) in all the bridges. It is however, obvious that the concrete in bridge 20-0085 is very different from the others. (In fact it was very much easier to drill out the cores). The diffusion coefficients were five times higher in this bridge. The depth of carbonation was extremely large in spite of the humidity being almost equal to the other bridges. Additionally, the relationship between RH and S_{cap} was different in this bridge. That is an indication of a deviating concrete quality (quite another *w/c*, see figure 4.2).

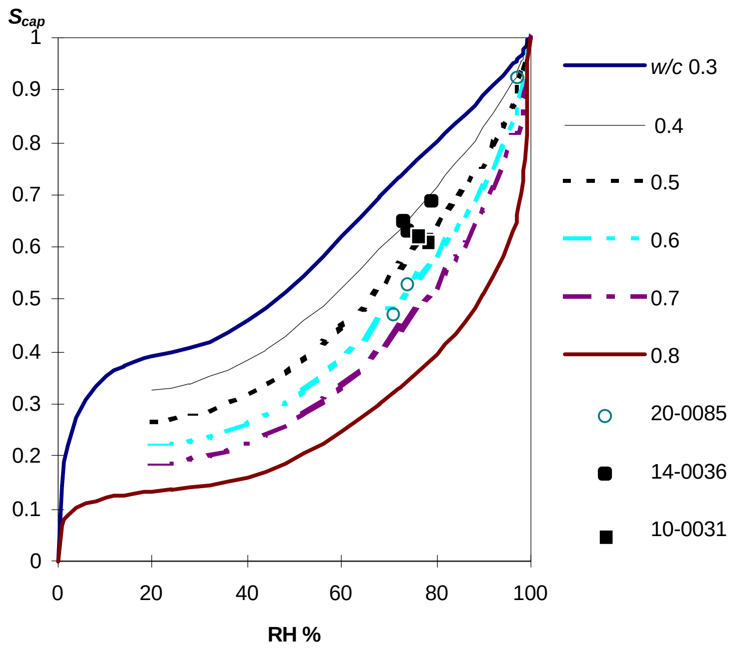

Figure 4.2. Relation between RH and S_{cap} , data from Nilsson [1980].

4.3 Effect of age

The bridges are 24 to 40 years old, and the five year period between the earlier and new chloride profiles is a relative short period in the life time of the bridges. Taking the remarks in Chapter 4.1 in respect, the difference in chloride ingress is smaller than the reproducibility of these measurements. The difference in the profiles, could be explained by the variability of the concrete and the micro environment. It is however important to note a slightly higher surface content in all cores from 1996. That is probably a combination of the weather just before the sampling and the fact that the surface analysis is from the outer 2 mm material, but slightly deeper in the 1991 and 1992 cores.

4.4 Effect of sampling point

The distance from the road and the height above the road seems to have a big influence on the chloride ingress. Even the orientation both geographically and relative to the traffic, is important.

4.5 Profile shape

The shape of the profiles varies from a plain profile of decreasing chloride content to profiles with a bump and one case a peak .The start of these peaks coincides with the depth of carbonation. Since carbonation dramatically reduces chloride binding, the carbonated layer only contains free chloride in pores, and then the total chloride content is reduced.

4.6 Effect of time of year

From the measurements in this investigation no conclusions could be drawn on the effect of the seasons. The bridge 14-0036 was earlier examined both in autumn and in springtime. The results are presented indicate a slightly higher surface concentration in the spring measurements.

4.7 Moisture profiles

The relative humidity profiles varies very little from bridge to bridge. In all bridges the profiles are between 70 to 80 % RH. This would be expected as they are all exposed to the same climate. There are bigger variations in degree of capillary saturation cf. section 6.2. The relationship between RH and capillary saturation varies with material properties such as water cement ratio and cement type. The moisture content is probably an important input to a chloride ingress model.

The RH-profiles are very flat i.e. there is little sign of wetting or drying. It seems as if the sampling points are not exposed to rain but more or less in equilibrium with the surrounding air humidity.

5. REFERENCES

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